Geothermal Heat Exchange:
A Good News / Bad News / Good News Story for the Environment

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1. Executive Summary

Carbon dioxide has been proven to be the root cause of climate change events such as global warming, extreme weather, and mass extinctions – which are threatening the planet as we know it. With UMass being the leading state institution for carbon emissions, Chancellor Subbaswamy created the Carbon Mitigation Task Force, which devised a plan for our campus to reach carbon net neutrality by 2032. The biggest component of this plan is to install a massive geothermal heat exchange (GHX) facility at UMass Amherst. Our team chose to investigate the dangers to our natural and built environments from such a GHX facility. The three problems that we chose to focus on were ground uplift due to drilling, cross-contamination of groundwater due to cracks/gaps in the geothermal grout, and determining the most environmentally friendly antifreeze solution to use within the system. Plausible solutions at UMass to mitigate these inherent risks are rotary drilling with a ground anchorage system, a low permeability grout mixture known as "mix 111", and propylene glycol as an eco-friendly antifreeze solution. The resistance forces of ground anchors and rotary drilling will limit the uplift of the ground to mitigate possible damage to the $30 million basketball center, adjacent to the installation site. The low permeability of "mix 111" and the low health hazard ratings of propylene glycol, will mitigate the risk of contaminating the Lawrence aquifer, a local drinking water source to UMass.

2. Introduction

The levels of carbon dioxide in our atmosphere have been linked to many disastrous effects on our planet, most notably global warming. Global warming is posing dangers such as rising sea levels and increased water temperatures due to the melting of glacial ice caps. These issues are presenting the risk of water overtaking landmasses, but also reduced food supplies due to the killing of marine wildlife [1]. In response, many institutions have set goals for reducing their carbon footprint. UMass is currently the leading carbon dioxide emitter among all state institutions in Massachusetts. Our Chancellor Subbaswamy created and charged the Carbon Mitigation Task Force to develop a plan for obtaining net-zero carbon emissions by the year 2030 [2]. The Geothermal Heat Exchange (GHX) project proposed is estimated to avoid 37.2% of the UMass carbon emissions, the largest of all proposed components of the Carbon Mitigation Plan [2]. The proposed GHX system will be a closed-loop borehole exchanger system to be installed under the Boyden Athletic Fields, with miles of piping to carry heat to and from campus buildings for heating and cooling. The intrusive nature of the installation and use of the geothermal heat exchange system will cause major, but what can we do to limit the adverse effects of the system to our local built and natural environments? In this paper, we investigate drilling and installation techniques, as well as system design elements that will limit the introduction of new problems through excessive damages. Although the potential environmental impacts from the GHX project can be severe, the interventions detailed below will strongly mitigate against serious harm, making a GHX facility that is good for the climate and our natural and built environments as well.

3. **Problem Statement**

The campus currently relies upon the Central Heating Plant (CHP) to provide heating to the campus through the combustion of natural gas. The Carbon Mitigation Task Force (CMTF) wrote a report that proposed the use of a large Geothermal Heat Exchanger (GHX) to eliminate 37.2% of the carbon emissions [2]. While this plan on carbon emissions looks bold, the solution to one problem introduces new problems to account for. The scale of the UMass system is much larger than average residential GHX systems that are commonly installed, with no more than 1-2 boreholes. The UMass system proposes to drill 2,490 boreholes at a depth of 800ft into the Boyden Athletic Fields [2]. This proposed location brings up the risks of structural damages to nearby buildings, such as the Champions Basketball Center and the Wastewater Treatment Plant. In a similar project in 2007 in Germany, the drilling of boreholes only about 500ft deep caused ground uplift to occur with a magnitude of surface-level change of 10 mm/month [3]. The drilling caused the swelling of an anhydrite layer underground, a geological structure characterized by ocean water mineral deposits [21]. The softness of the anhydrite layer allowed for the absorption of drilling fluids leading to expansion and eventual ground uplift. This anhydrite layer in the German project is similar to the first layer of varved clay here at UMass [4,5], at an underground depth of 0 to 140 ft. Varved clay is made up of alternating layers of glacial deposits that consist of groundwater flow throughout it [4,22]. Varved clay is susceptible to moisture absorption, which will alter the volume of the layer, thus creating conditions required for ground uplift as it occurred in the German installation project [6]. The damages that occurred in Germany can be seen below in Figure 1. Major structural cracks and damages to water lines occurred. The proximity of the UMass Basketball Champions center to the proposed GHX site at

UMass puts it at risk for similar damages. The GHX system comes with a high price tag of approximately $96 million. Damages to a nearly $30 million building would add a hefty repair cost on top [2,7]. The drilling of boreholes poses major concerns for the structural environment surrounding the GHX, but there are also concerns surrounding the natural environment that come along with the system.

Figure 1: Structural damages that occurred in Staufen, Germany due to ground uplift from borehole drilling [3].

The GHX system can cause environmental problems for the Lawrence aquifer considering the possibility of antifreeze leakage and groundwater contamination. The borehole system comprises a few components from the piping and a heat transfer fluid, along with a geothermal grout that is the structural support to the entire system. The grout layer is essential for structural support of the borehole piping and the surrounding ground to prevent collapse as shown in figure 2. The grout is most commonly made of a water/cement mixture that must have a specific composition ratio to ensure optimal thermal conductivity, as well as structural support properties [8]. Contamination of groundwater due to discontinuities in the grout can lead to the pollution of local drinking water sources [8]. This ability to travel through a solid is the permeability of the solid, and in the case of grout, this is determined by the ratio of sand, cement, and water, as these dictate the gradient of the particle size distribution [8]. The varved clay layer discussed above is approximately the first 140ft of the ground and is housing groundwater flow that will come into contact with the borehole system [4]. Along with natural water sources and contaminants, the leakage of the transfer fluid within the piping should also be accounted for.

The heat transfer fluid is a dilute antifreeze solution that can be leaked and mix and pollute underground water flow. Structural damages and or corrosion of the piping that results in a leak should be a factor that is assumed to occur with the long-term use of this system. With the Lawrence aquifer being local to the Amherst area, contaminants in underground water can be carried to this aquifer, which is a source for 40% of the local drinking water [9]. Limiting the transfer of fluids or contaminants through the grout is an essential step to protecting drinking water sources.

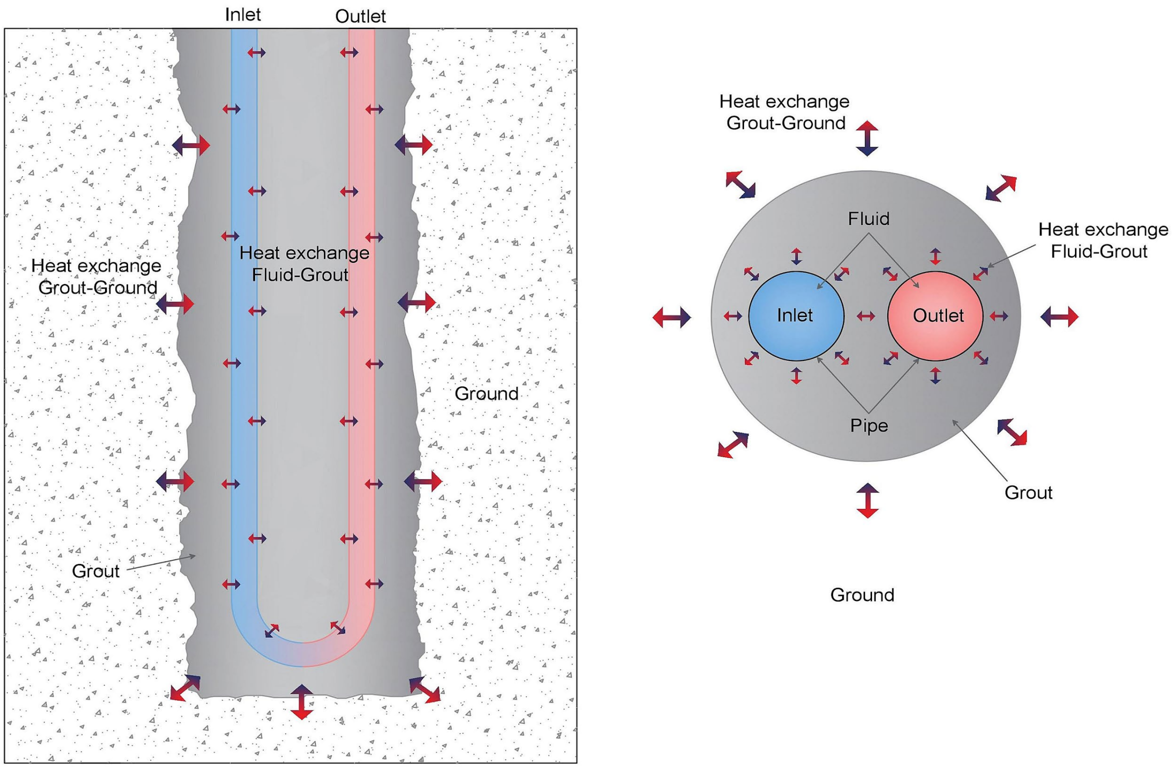

Figure 2: Schematic displaying the role that geothermal grout plays within the borehole system concerning structural integrity [20].

Implementing the GHX system in a manner that limits the damages occurring to UMass's natural and built environments should be a major concern of the UMass administration. Accounting for these problems will allow UMass to make a major impact on carbon emissions without inflicting additional harm. Towards this end, we have researched the installation methods and system design features that accommodate the UMass geology in preventing such impacts.

4. **Solution Technology & Implementation Plan**

As discussed in previous sections, there are major risks when implementing a GHX system; choosing specific installation and design features is crucial to avoiding excess damages. Choosing proper drilling techniques and anchoring equipment, a specific grout mixture, and a specific diluted antifreeze are among the requirements that must be met for UMass to limit the environmental damages that can be caused by the GHX.

UMass campus geology needs to be considered when considering various design options. Land uplift due to borehole drilling can cause devastating damage to surrounding campus infrastructure, as it occurred in Staufen, Germany. The drilling of 800 ft deep boreholes can make it more likely that uplift will occur, so UMass must consider methods to reduce this. The first 140 feet of UMass's geology consist of silty clay, with small, sand-like sediments that pose the greatest risk of uplift [4]. The next 600 feet is the bedrock, and while harder to drill into, poses less of a threat [4]. The basketball athletic facility is nearest to the athletic fields; as such, protecting this building becomes a priority. The option of ground anchors offers a great solution for protecting this building. At 200 feet below, the anchor will be installed to meet bedrock, to apply a resistance load to limit the soil uplift force. Attached to the anchor is a device called the anchor bond length, which is a portion of steel that moves freely over a tendon [10]. The steel tendon acts as a bar that is pulled into tension to prevent any movement. This anchor bond length transfers any resisting force to the structure, thus preventing uplift. This portion of the anchor will be placed behind the soil that is most vulnerable to uplift. Umass's geology varies as depth increases, so the proper design and installation methods described above must be implemented.

The type of anchor that will work best for the geology of UMass is the straight shaft pressure, grouted-ground anchors. Out of three different types of anchors considered, these are mostly used in weaker, fissured rocks and fine-grained soils[10]. The straight shaft anchors are gentle enough to be placed into weaker soils while having the strength to prevent uplift. This grouting procedure increases the resistance force of the ground and limits uplift. The grout ratio and makeup will have to be considered to reduce leakage. Figure 3 is an example of the type of anchorage system UMass should consider utilizing based on the geologic makeup.

The type of drilling method used can also cause serious ground uplift, capable of damaging the surrounding environment. Softer silty clay positioned close to the surface of the fields should be drilled into with a smaller diameter stem drill. Failure to be cautious of this will cause the drill to remove larger amounts of soil, which can lead to greater uplift in future years.

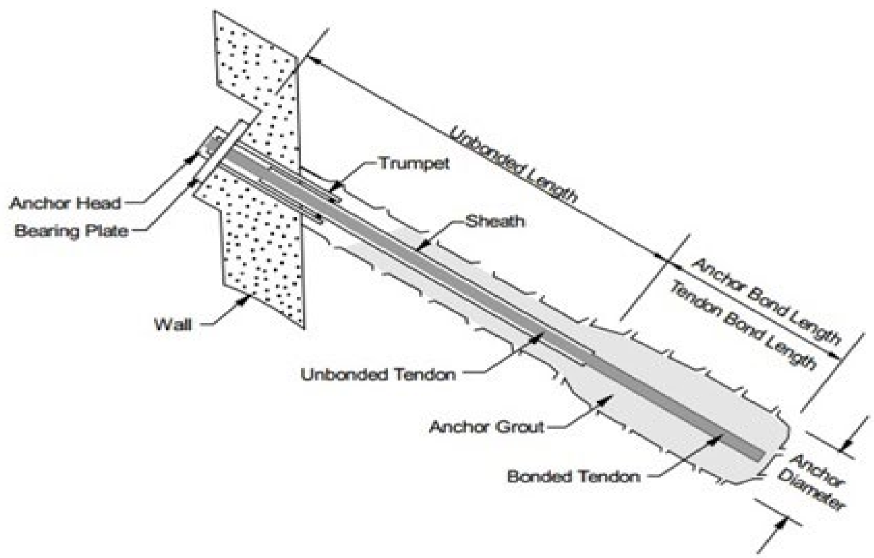

Figure 3: Diagram of a straight shaft pressure anchor [10]

The ratio of geothermal grout mixture is vital in limiting the chances of cross contamination in groundwater. A field study at the Brookhaven National Laboratory determined the different performance characteristics for various grout mixtures in comparison to those of a mixture "111", as shown in **Appendix A** [17]. The energy efficiency of geothermal heat exchange depends upon the thermal conductivity of the grout, as resistances will limit heat transfer into the antifreeze solution [24]. The grout mixture, "mix 111" examined in the Brookhaven study was the grout that showed the greatest potential for mitigating the risks of cross-contamination while maintaining thermal performance. The thermal conductivity of the mixture was proven to remain at 2.160 ±

0.038 (W/m*K) when fully set [17]. This value is substantially higher by a factor of nearly 2.5 than other grouts tested, which returned values between 0.803-0.868 (W/m*K) [17]. Figure 4 shows the permeability of mix 111 compared to those from three other cement mixtures, and the permeability of mix 111 is substantially lower [17]. With the Lawrence aquifer near UMass and water flow through the varved clay layer (0-120ft), low permeability will limit cross-contamination of these water systems, preserving the current state of the ecosystems as much as possible. [4, 9]. Overall, these results show that grout mix 111 has both high thermal conductivity for energy efficiency, and low fluid permeability to limit groundwater contamination, making it the grout of choice for the UMass GHX system.

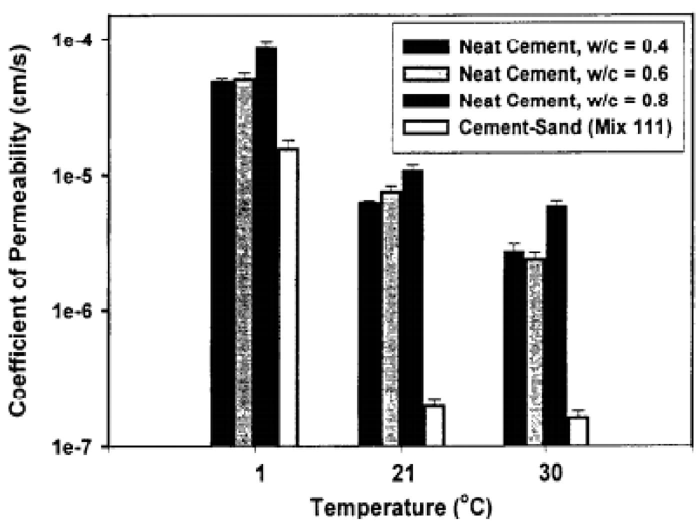

Figure 4: Graph comparing the permeability of the grout mixtures

The Brookhaven study discovered the ideal composition of the grout mixture 111 which is listed in **Appendix B**. The grout mixture can have a specific gradient that alters the thermal conductivity based on sand particle size [18]. When accounting for the water flow through the varved clay layer, having a smaller sand particle size reduces the spacing between the particles, thus making for a tighter gradient [9,17]. Another additive that can be used as the main component for grouts is bentonite, a clay powder that can increase the thermal performance of a grout. It is much more cost-effective to use it in small amounts as the price is much higher than cement. The bentonite can make the grout more stable while decreasing the viscosity of the liquid grout, to allow for easier injection to the boreholes [18]. The mix, as shown in **Appendix A,** has high thermal conductivity to maintain the efficiency of the system, but also provides a low permeability to limit the flow of water and contaminants to a new ecosystem.

Another important consideration in protecting the environment from the geothermal exchange is the proper choice of antifreeze in the heat transfer fluid that runs through the borehole piping. That's because small leaks of antifreeze can cause downstream environmental problems as detailed in the previous section. Heinonen and coworkers performed a study of six different antifreeze solutions used in ground-source heat pump systems based on the following risks: fire hazard; corrosion and leakage; health hazard; environmental; detailed heat pump system analysis to predict annual energy use, life-cycle cost, power plant emissions; and regulatory risk for future use [12]. Each antifreeze solution was rated based on the potential for problems and the results can be seen in **Appendix C**. Environmental risk assessment evaluated emissions (of carbon dioxide, sulfur dioxide, nitrous oxide, and mercury) and the volume of ground and surface water that could be polluted due to leakage. Federal and state environmental regulations were used to determine which antifreeze solutions were within regulation. This study determined the most appropriate antifreeze solution to be propylene glycol due to its lack of environmental impacts.

While propylene glycol was found to have an overall low risk in all evaluated areas, the analysis predicted it would have a higher energy use due to its higher viscosity which requires more energy flow through the pipes. Ethanol and methanol exhibit a high fire risk in pure forms but a lower risk in their diluted forms. Ethanol, methanol, and urea each had reported issues relating to corrosion of metal particles in piping and joints, specifically those with iron and copper piping. UMass should not utilize these specific antifreeze solutions because UMass campus geology contains iron minerals in the strata containing clay and in the bedrock layer containing quartz sand [4]. Further, methanol had high environmental and health risks due to its toxicity particularly relating to water pollution. Potassium acetate, calcium magnesium acetate, and urea had high leakage risks ranging from moderate to massive leakage [12]. Based on this study, the best choice for an antifreeze solution at UMass is propylene glycol due to its overall low risk in all areas. The only drawback to propylene glycol is relatively high life-cycle costs due to its higher viscosity which requires the consumption of more energy to flow it through the pipes. However, the aforementioned life-cycle cost outweighs the immense potential external costs related to the mitigation of environmental damage resulting from leakage of the other antifreeze solutions into the local ecosystem.

To summarize, the installation of a geothermal heat exchanger at UMass can cause significant environmental damages if the correct techniques and design features are not used. Because the geology of UMass's campus is composed of silty and varved clay near the surface, to prevent ground uplift when drilling, a straight shaft pressure grout anchor should be implemented so the resistance force underground is stronger than the uplift force. Drilling techniques for boreholes should consist of smaller drills with softer soils as larger intrusive drills are more probable for ground uplift. Secondly, Filling the boreholes should be done with "mix 111" geothermal grout. It provides great thermal conductivity for system efficiency but also has very low permeability to limit the ability of cross-contamination of water sources and underground ecosystems. Finally, based on studies and UMass campus geology, propylene glycol is the best antifreeze solution for UMass's geothermal heat exchanger system transfer fluid for limited environmental damage. Compliance with these solutions will allow UMass to limit the environmental impact on the local ecosystems when using the geothermal exchange to reach their net-zero goal.

5. **Pros and Cons of Our Proposed Solutions:**

The GHX system advantageously provides major carbon emission reductions on campus, however, there are some drawbacks that UMass needs to consider. For environmental wellbeing, several choices will provide UMass with reliable safety standards, these, however, must be monitored and tested periodically. For social equity considerations, leakage of antifreeze may cross-contaminate water in communities nearby the installation which is not directly benefiting from the GHX system. These non-benefiting, impacted communities would suffer from the resultant environmental damage, and the safety of the community would be compromised. Economically, the GHX system we've designed proves to be more expensive to prioritize environmental and human safety. As previously mentioned, higher energy usage requires more power consumption for the entire system. With these pros and cons, there are techniques to mitigate the possible consequences of GHX, while emphasizing the positive attributes.

Environmental

When deciding what diluted antifreeze to use, propylene glycol is the most common choice for geothermal energy. Propylene glycol is the standard choice for antifreeze due to its reliability and lack of risks associated with corrosion, flammability, and toxicity. Antifreeze disposal can be carried out by local companies which can store, dispose, or recycle the antifreeze solution [23]. If the antifreeze is recyclable, the company will treat it before reselling the solution [13]. Concerning human health impacts of propylene glycol exposure, there are government regulations and guidelines in place to protect public health from any adverse effects. Propylene glycol has been classified as "generally recognized as safe" by the Food and Drug Administration (FDA) and it is acceptable for use in food additives, flavorings, drugs, and cosmetics [14]. Nonhuman impacts of propylene glycol can happen due to system leakage; however, propylene glycol can break down relatively quickly (within several days to a week) in surface water and soil [15]. Animal studies have shown no adverse effects on reproductive abilities [15].

The straight shaft anchor chosen will reduce the amount of ground uplift seen, and there are few implications on the system. The geology at UMass is ideal for the anchor, however, if too large a diameter drill is used, this can lead to environmental damage to the soil. For this reason, sample boring and testing need to be implemented before drilling [11]. If the size of the drill head is not considered, UMass could see potential uplift and damage to nearby buildings in the years to come.

Equity

Despite the environmental advantages of switching to a geothermal system for heat and cooling, UMass must consider the social equity of this solution. The major consideration is whether impacts on groundwater affect drinking water. Another consideration is how the antifreeze solution will be disposed of. The disposal of antifreeze must be tracked and monitored to avoid being subjected to marginalized communities; with the disposal of many materials, waste sites tend to be near lower-income areas. However, with agencies being able to treat and repurpose antifreeze [23], this limits the need to dispose of the materials.

Impacts on groundwater can be mitigated by choosing the appropriate grout mixture. The low permeability that was achieved through the testing and design of mixture 111 for geothermal grout limits the cross-transfer of liquids or contaminants through it [17]. The grout in place in the varved clay layer will be subjected to underground water flow which could be cross-contaminated if the grout allows for the flow of contaminants to this layer [4]. The Lawrence aquifer, local to UMass, provides drinking water to many of the residents in the area [9]. Cross-contamination due to pathways in the grout could lead to unhealthy drinking water for the area, impacting their quality of life if this was not accounted for.

Overall, these solutions proposed in the previous chapter do not imply social equity issues. We encourage UMass to continue to ask for community input to avoid social equity issues related to switching to a geothermal system. Further, UMass must be fully transparent with the community to avoid social equity issues down the road.

Economics

The innovations in environmentally friendly technology usually come with a higher price tag. If the greener alternatives were the cheapest options, it's safe to say that our planet would be in much better condition. Assessing the value of environmentally friendly alternatives is important when diving into the costs associated with new advancements.

A techno-economic and environmental analysis of propylene glycol, used in ground source heat pumps, has been established from analyzing 36 case studies in six different climate zones [16]. The economic analysis was performed on a life cycle of 25 years considering the installation and operation costs [14]. Using this antifreeze solution rather than water has a higher operational cost due to antifreeze additives costing money and requiring replacement every five years [14]. Compared to water, antifreeze solutions have a lower installation cost due to shorter drilling distances and shorter pipe loops [14]. Due to the higher antifreeze costs and circulation pump life cycle costs, propylene glycol appears to be the most expensive solution.

While propylene glycol is the more expensive solution, the straight shaft anchors that will be used are also less economical. The boreholes are estimated to cost on average $4,100 per unit [10]. Boreholes will be placed alongside the basketball athletic center, which is 209 feet in length.

10 boreholes will be drilled 20 feet apart alongside the wall of the building, equating to an estimated cost of $41,000. The athletic fields have an area of 1,405,426 sq. ft, and the boreholes will only take up an area of 1,000 sq. ft. This, however, will mitigate delays and construction costs in the rest of the fields.

Energy

The thermal conductivity of the grout is a determining factor for the performance of the system with its grout. Grout mixture 111 had a thermal conductivity of 2.160±0.038 (W/m*K) which represents a factor of nearly 2.5 greater than the second-best mixture tested at the Brookhaven National Laboratory [17]. Having a high conductivity will increase the amount of heat drawn per second and thus reduces the run time to achieve the desired temperature.

While propylene-glycol offers numerous advantages, a major downside in comparison to other antifreeze solutions is the viscosity differences. The viscosity of propylene-glycol is 0.042(N*s/m^2) where other common additives, such as ethanol and methanol, are 0.001 and 0.00056 (N*s/m^2) respectively [16]. The large increase in viscosity takes its toll on the physical pump that pushes the fluid in and out of the boreholes. The higher the viscosity, the higher the resistance to flow, which will require a larger amount of energy to power the system.

Overall, the solution that was proposed has a large amount of potential within it and very few drawbacks. The major drawbacks were linked to increased costs, but with new technology to mitigate impacts, increased costs are inevitable. The solution outlined will help UMass limit its environmental damage when implementing and running a Geothermal Heat Exchange system.

6. Conclusion

Our team has researched the potential solutions to mitigate the environmental damages when implementing the GHX system at UMass. The CMTF report shows strong evidence backing the use of a GHX to reach the campus goal of carbon neutrality by 2030. As UMass moves forward with an estimated $96 million project, they must ensure the integrity of our built and natural environments. The installation of the UMass project requires the drilling of 2,490 boreholes that will be set 800ft deep under the Boyden Athletic Fields. The first 140ft of our geology is a varved clay layer, a layer susceptible to moisture absorption, which could result in major ground upswelling when drilled into as occurred in Staufen, Germany. The use of ground anchorage systems to prevent the drilling uplift does require a higher upfront cost estimated to be $41,000, this fails in comparison to the cost of repairs to the Basketball center that cost an estimated $30 million. The location of the GHX system will be through the varved clay layer which is also stated to have groundwater flow that will meet the system. Limiting the contamination of the groundwater is crucial as the Lawrence Aquifer, local to UMass, provides 40% of the drinking water for the community. The choice of a specific grout mixture, mix 111, granted the properties of low permeability while maintaining a 148% increase in thermal conductivity to that of the next best grout. The low permeability of the grout limits the gaps in the solid that would allow for water or contaminants underground to travel through and come into contact. Preventing the passage of outside materials through the grout also shows promise for limiting the transmission of leaked antifreeze from getting into the groundwater. With long-term use of the GHX system, it can be assumed that normal wear and tear will eventually create leakage of antifreeze. The choice of Propylene Glycol offered the most promising when compared to other common GHX fluid solutions. It ranked highly in areas such as corrosion or fire risks, as well as health hazard risks. This choice does also come with a higher cost, but no value of money should replace the assurance of human health safety. Mitigating the risk of contamination of the local drinking water can be achieved with these two design features that offer increased thermal properties, to maintain optimal efficiency of the GHX system. The implementation of a geothermal heat exchange system is deemed essential for meeting the UMass goal of carbon neutrality, but solving one problem should not create others. Our report indicates precisely how to avoid such downstream problems.

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8. Acknowledgements:

- We would first like to thank one of our iCons 2 Energy professors, Dr. Scott Auerbach, for being the essential support for our successful research project. He devoted hours of his time to not only meet with us and provide helpful constructive criticism but also granted his time outside of the class. He lent his support beyond academics and beyond the scope of this project to ensure that we grew as more than just students through the experiences of this course.
- We would also like to thank our second iCons 2E professor, Christine McGrail, for being an essential piece to the iCons 2E course. Numerous times she was able to quickly alter and develop lesson plans to ensure that we as students were getting the most out of each experience in the course, to prepare us to be able to share our best work.
- We would also like to give a special thanks to Dr. Stephen Mabee, Massachusetts State Geologist. Dr. Mabee was kind enough to give us crucial information on the geology of campus that he had obtained. This information became the foundation of all our research and this project would not have been possible without his generosity.

9. Appendices

Appendix A: Structural Properties of mix 111.

Structural Characteristic (units)	Tested Value from Brookhaven Lab
Compressive Strength (MPa)	36.7 ± 4.2
Flexural Strength (MPa)	6.35 ± 0.72
Splitting Tensile Strength (MPa)	6.01 ± 0.48
Elastic Modulus (GPa)	13.8 ± 0.9
Poisson Ratio	0.21 ± 0.02

The physical properties of mix 111 are shown above. These values are relatively similar to that of other groups [17].

Grout Mix	Bond Strength (kPa)
47 (w/c=0.4)	3.6 +/- 0.7
108	72.4 +/- 12.9
109	73.0 +/- 10.3
110	47.0 +/- 10.8
111	150 +/- 20.5
111+ CaO	69.5 +/- 13.4

The table above shows the relative bond strengths of each of the grout mix tested and it clearly shows that mix 111 is highly superior [17].

Appendix B:

Cement	**1 x 94lb bag**
Water	**23.5 liters (6.19 U.S. gallons)**
Sand (conforming to spec.)	**1 x 100 lb. bags**
Superplasticizer	**639 ml (21 fl. oz) (approximately not to exceed 851 ml)**
Bentonite (optional)	**470 g (1.04lb)**
Yield	**72.2 litres (19.1 U.S. gallons)**

The information in the table above is the recipe determined to be the ideal grout. This mixture ratio is the mixture by the name of mix 111 [18].

Appendix C:

Category	Methanol	Ethanol	Propylene Glycol	Potassium Acetate	CMA	Urea
Life-Cycle Cost	✪✪✪	✪✪✪	✪✪[1]	✪✪[1]	✪✪[1]	✪✪✪
Corrosion	✪✪[2]	✪✪[3]	✪✪✪	✪✪	✪✪[4]	✪[5]
Leakage	✪✪✪	✪✪[6]	✪✪[6]	✪[7]	✪[8]	✪[9]
Health Hazard Risk	✪[10,11]	✪✪[10,12]	✪✪✪[10]	✪✪✪[10]	✪✪✪[10]	✪✪✪[10]
Fire Risk	✪[13]	✪[13]	✪✪✪[14]	✪✪✪	✪✪✪	✪✪✪
Environmental Risk	✪✪[15]	✪✪[15]	✪✪✪	✪✪[15]	✪✪[15]	✪✪✪
Risk of Future Use	✪[16]	✪✪[17]	✪✪✪	✪✪[18]	✪✪[19]	✪✪[19]

Key:

✪	Potential problems, caution in use required
✪✪	Minor potential for problems
✪✪✪	Little or no potential for problems

Category	Notes
Life-Cycle Cost	1. Higher than average installation and energy costs.
Corrosion	2. High black iron and cast iron corrosion rates. 3. High black iron and cast iron, copper and copper alloy corrosion rates. 4. Medium black iron, copper and copper alloy corrosion rates. 5. Medium black iron, high cast iron, and extremely high copper and copper alloy corrosion rates.
Leakage	6. Minor leakage observed. 7. Moderate leakage observed. Extensive leakage reported in installed systems. 8. Moderate leakage observed. 9. Massive leakage observed.
Health Risk	10. Protective measures required with use. See MSDS. 11. Prolonged exposure can cause headaches, nausea, vomiting, dizziness, blindness, liver damage, and death. Use of proper equipment and procedures reduces risk significantly. 12. Confirmed human carcinogen.
Fire Risk	13. Pure fluid only. Little risk when diluted with water in antifreeze. 14. Very minor potential for pure fluid fire at elevated temperatures.
Environmental Risk	15. Water pollution risk.
Risk of Future Use	16. Toxicity and fire concerns. Prohibited in some locations. 17. Toxicity, fire, and environmental concerns. 18. Potential leakage concerns. 19. Not currently used as GSHP antifreeze solutions. May be difficult to obtain approval for use.

The chart above is the results from the tests run on the different antifreeze solutions. The comparison of these results was used for determining our selection [16].

Calculations:

Determining the percent increase in grout thermal conductivities:

Mix 111 Conductivity = 2.16(W/m*K) Second Best Grout conductivity = 0.868(W/m*K)

((2.16-0.868)/0.868) *100=148% increase in conductivity.

Determining the number of boreholes alongside the basketball athletic facility:

Estimated cost per borehole unit: $4,100

Length of basketball athletic facility: 209 ft.

Distance between boreholes alongside one wall of the facility: 10 ft.

(209 ft.)/(20ft.)=10.45 *estimated to 20 boreholes (2 lines) alongside one wall

$4,100*20 boreholes= $82,000 total

- This calculation assumes two lines of boreholes. It is unclear whether additional lines of boreholes will be needed.